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Discovery of the Narrow-Line Seyfert 1 galaxy Mkn 335 in an historical low X-ray flux state

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ABSTRACT

We report the discovery of the Narrow-Line Seyfert 1 galaxy Mkn 335 in an extremely low X-ray state. A comparison of *Swift* observations obtained in May and June/July 2007 with all previous X-ray observations between 1971 to 2006 show the AGN to have diminished in flux by a factor of more than 30, the lowest X-ray flux Mkn 335 has ever been observed in. The *Swift* observations show an extremely hard X-ray spectrum at energies above 2 keV. Possible interpretations include partial covering absorption or X-ray reflection from the disk. In this letter we consider the partial covering interpretation. The *Swift* observations can be well fit by a strong partial covering absorber with varying absorption column density ($N_{\rm H} = 1 - 4 \times 10^{23}$ cm^{-2}) and a covering fraction f_c=0.9 - 1. When corrected for intrinsic absorption, the X-ray flux of Mkn 335 varies by only factors of 4-6. In the UV Mkn 335 shows variability in the order of 0.2 mag. We discuss the similarity of Mkn 335 with the highly variable NLS1 WPVS007, and speculate about a possible link between NLS1 galaxies and broad-absorption line quasars.

Subject headings: galaxies: active, galaxies: individual (Mkn 335), galaxies: Seyferts, X-rays: galaxies

1. Introduction

Since the mid 1980s Narrow-Line Seyfert 1 galaxies (NLS1s; Osterbrock & Pogge 1985) have become a field of extensive study in AGN science. NLS1s are crucial for our understanding of the AGN phenomenon, because they are most likely AGN at an early stage (e.g. Grupe 2004). They possess relatively low-mass black holes and high Eddington ratios $L/L_{\rm Edd}$. NLS1s are characterized by extreme properties, such as steep soft and hard X-ray spectra, strong X-ray variability, and strong optical Fe II emission (e.g. Boller et al. 1996; Leighly 1999a,b; Grupe et al. 2001; Grupe et al. 2004a; Boroson & Green 1992).

The NLS1 Mkn 335 ($\alpha_{2000} = 00^{\rm h}06^{\rm m}19.^{\rm s}5$, δ_{2000} = $+20°12'11.''0$, z=0.026) is a well-known bright soft X-ray AGN and has been the target of most X-ray observatories. It was seen as a bright X-ray AGN by UHURU (Tananbaum et al. 1978) and EINSTEIN (Halpern 1982). Pounds et al. (1987) reported a strong soft X-ray excess found in the EXOSAT spectrum, which was confirmed by BBXRT observations (Turner et al. 1993). GINGA observations of Mkn 335 suggested the presence of a warm absorber in the source (Nandra & Pounds 1994). During ROSAT observations it also appeared bright and with a strong soft X-ray excess (Grupe et al. 2001). The X-ray spectrum during the 1993 ASCA observation (George et al. 2000) was either interpreted by the presence of a warm absorber (Leighly 1999b) or by X-ray reflection on the disk (Ballantyne et al. 2001). Beppo-SAX observations of Mkn 335 also confirm the presence of a strong soft X-ray excess (Bianchi et al.

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2001) and a small or moderate Compton reflection component. *XMM-Newton* observed Mkn 335 in 2000 and again in 2006 (Gondoin et al. 2002; Longinotti et al. 2007a; Longinotti et al. 2007; O'Neill et al. 2007). Mkn 335 is exceptional in showing evidence for an unusually broad wing in the iron line (Longinotti et al. 2007a). The wing is required, if the XMM spectrum is explained in terms of reflection; it is not, if a partial covering interpretation is adopted. High-amplitude variability provides important new constraints to distinguish between these different spectral models. Mkn 335 was observed by *Swift* (Gehrels et al. 2004) in 2007 May and appeared to be dramatically fainter in X-rays than seen in all previous observations. In this letter we report on this historical low X-ray flux state of Mkn 335 and compared the continuum properties of the *Swift* with previous *XMM-Newton* observations.

Throughout the paper spectral indexes are denoted as energy spectral indexes with $F_\nu \propto \nu^{-\alpha}$. Luminosities are calculated assuming a ΛCDM cosmology with $\Omega_{\rm M}$=0.27, Ω_Λ=0.73 and a Hubble constant of H_0=75 km s^{-1} Mpc^{-1} corresponding to a luminosity distance D=105 Mpc. All errors are 90% confidence unless stated otherwise.

2. Observations and data reduction

Swift observed Mkn 335 on 2007 May 17 and 25 and June 30 to July 02 for 4.8, 8.2, and 8.7 ks (Table 1), respectively, with its X-Ray Telescope (XRT) in Photon Counting mode (PC mode) and in all 6 filters of the UV-Optical Telescope (UVOT). X-ray data were reduced with the task *xrtpipeline* version 0.11.4. Source and background photons were extracted with *XSELECT* version 2.4, from circles with radii of $47''$ and $189''$, respectively. The spectral data were re-binned with at least 20 photons per bin *grppha* version 3.0.0. The 0.3-10.0 keV spectra were analyzed with *XSPEC* version 12.3.1x (Arnaud 1996). The auxiliary response files were created with *xrtmkarf* and corrected using the exposure maps, and the standard response matrix *swxpc0to12_20010101v008.rmf*.

The UVOT data were coadded for each segment in each filter with the UVOT task *uvotimsum* version 1.3. Source photons in all filters were selected in a circle with a radius of $5''$. UVOT magnitudes and fluxes were measured with the task *uvotsource* version 3. The UVOT data were corrected for Galactic reddening ($E_{\rm B-V}$ = 0.035; Schlegel et al. 1998).

XMM-Newton observed Mkn 335 in 2000 and 2006 for 37ks and 133 ks, respectively (see Table 1). During the 2000 observation the Optical Monitor (OM) did photometry in the V, B, U, and M2 filters. During the 2006 observation the UV grism was used exclusively. The *XMM-Newton* EPIC pn data were analyzed using the XMM-SAS version *xmmsas_20060628_1801-7.0.0*. The 2000 amd 2006 observations were performed in full-frame and small window, respectively. Because the 2000 observation was severely affected by pileup, photons from a $20''$ source-centered circle were excluded. The source photons in the 2006 pn data were selected in a radius of $1'$ and background photons of both observations from a source-free region close by with the same radius. The spectra were rebinned with 100 photons per bin. In order to compare the photometry in the OM with the UVOT we selected 5 field stars with similar brightness in V as Mkn 335. Only in B and M2 the OM magnitudes had to be adjusted by -0.10 mag and $+0.30$ mag, respectively.

3. Results

None of the *XMM-Newton* and *Swift* spectra can be fitted by a single absorbed power law model. In the literature a variety of spectral models have been applied to the X-ray data of Mkn 335, including warm absorption (Leighly 1999a; Nandra & Pounds 1994), partial covering (Tanaka et al. 2005) and reflection (Gondoin et al. 2002; Ballantyne et al. 2001; Crummy et al. 2006; Longinotti et al. 2007a; Longinotti et al. 2007). Fits with a warm absorber model (*absori*) and blackbody plus power law model yield unacceptable results. While fits to the *XMM-Newton* 2000 data yield acceptable fits by using an absorbed broken power law model with the absorption column density fixed to the Galactic value (3.96×10^{20} cm^{-2}; Dickey & Lockman 1990), the *XMM-Newton* 2006 and *Swift* spectra require additional components. We used a partial covering absorber model with an underlying power law and broken power law spectral models. Table 2 summarizes the results from the X-ray spectral analysis. Figure 1 displays the *Swift* spectra fitted

with a power law and partial covering absorber. Fits to each spectrum were first performed separately. Subsequently all the *Swift* spectra were fitted simultaneously in XSPEC with the power law spectral slopes tied and the absorber parameters and the normalizations left to vary. The results are listed in Table 2 and suggest a development of the partial covering absorber over time. The most dramatic change is from the 2006 *XMM-Newton* to the first *Swift* observation when the absorber became nearly opaque and only 2% of the X-ray emission can be seen directly. In this case the absorption column density changes from 5×10^{23} cm^{-2} with a covering fraction of 0.45 during the 2006 *XMM-Newton* observation to about 4×10^{23} cm^{-2} and a covering fraction of 0.98 during the first Swift observation.

We fitted all three *Swift* spectra simultaneously in XSPEC by tying the covering fraction f_c and spectral indices together. This fit suggests a change in the absorption column density $N_{\rm H,pcf}$ of the partial covering absorber by a factor of 2 within a week between the 2007 May 17 and 25 observations. Alternatively, we also fitted the spectra with $N_{\rm H,pcf}$ tied and f_c left as a free parameter. An F-test gives an F-value of 7.8 that these two fits are different and a probability P=0.006 of a random result. Leaving $N_{\rm H,pcf}$ free gives a significantly better result than leaving f_c free to vary. In the rest-frame 0.2-2.0 keV band the observed fluxes (only corrected for Galactic absorption) seem to be highly variable and between the *XMM-Newton* 2000 and the first *Swift* observation we found variability by a factor of 30. However, when correcting also for intrinsic absorption the unabsorbed restframe 0.2-2.0 keV fluxes from ROSAT to Swift are comparable. During the ROSAT All-Sky Survey observation a flux of $4{\times}10^{-14}$ W m^{-2} was found (Grupe et al. 2001). Correcting for a partial covering absorber in the *XMM-Newton* and *Swift* spectra we found that the flux varied only by factors of 4-6 as listed in Table 2.

The X-ray spectra of Mkn 335 in the higher and more typical flux state can be well described as arising from an incident power law and reflection component (e.g. Crummy et al. 2006; Longinotti et al. 2007a). However, the low-flux spectra are difficult to reproduce by simply rescaling the high-state models or by varying the relative contribution of each component. A modified reflection model, which self-consistently describes the high- and low-flux states is being investigated and is presented in Gallo et al. (in prep).

As shown by the spectral energy distribution (SED) in Figure 2 there was no dramatic variability in the UV data between the 2000 *XMM-Newton* OM and 2007 *Swift* UVOT observations, although during the 2007 May 17th observation Mkn 335 was about 0.2 mag fainter. The UV/optical spectral slopes are on the order of $\alpha_{\rm UV} = -0.4$, except for the 2007 May 17 observation when it was $\alpha_{\rm UV} = -0.3$. The UV to X-ray spectral slope $\alpha_{\rm ox}$[1] was significantly steeper during the *Swift* observations with $\alpha_{\rm ox}$=1.91 and 1.65 during the *Swift* segments 001 and 002, respectively. During the 2000 *XMM-Newton* observation, however, an $\alpha_{\rm ox}$=1.32 was measured, consistent with the value given by Gallo (2006).

4. Discussion

We reported the *Swift* observations of the NLS1 Mkn 335 when it was in its lowest X-ray flux state ever observed. Historically, Mkn 335 has exhibited X-ray variability by about a factor of a few (e.g. Turner et al. 1993; Markowitz & Edelson 2004), although the source has always[2] remained rather bright at least until the last X-ray observation with *Suzaku* in 2006 June (J. Larsson, 2007 priv. comm.). However, sometime between 2006 June and 2007 May the observed flux dropped by a factor of more than 30 including a dramatic change in its SED. The X-ray spectrum has become progressively more complex as the X-ray flux has diminished, indicative of either absorption or reflection (e.g. Gallo 2006). The 2-10 keV high-flux spectrum in 2000 did not appear overly complex and the high-energy continuum could be simply fitted with a power law. The 2006 *XMM-Newton* data, however, can be fitted with a partial covering absorber model (see also O'Neill et al. 2007), suggesting that the absorber started moving in the line of sight before 2006 January.

Partial covering of the central light source has

[1]The X-ray loudness is defined by Tananbaum et al. (1979) as $\alpha_{\rm ox}$=–0.384 $\log(f_{\rm 2keV}/f_{2500\mathring{A}})$.

[2]Except for an episode in 1983 when it had a rather low X-ray flux during its EXOSAT observation as reported by Pounds et al. (1987)

been invoked since the early days of AGN X-ray spectroscopy (e.g. Holt et al. 1980), and quite often to describe the X-ray spectrum of NLS1 (e.g. Gallo et al. 2004; Grupe et al. 2004b; Tanaka et al. 2005). Its presence is also indicated by narrow absorption lines (which appear to be saturated but do not reach zero intensity) in UV spectra of Broad Absorption Line (BAL) quasars (e.g. Barlow et al 1997; Hamann 1998; Wills et al. 1999). However, the geometry and physics of partial coverers are still not well understood. One possible geometry consists of thick blobs of gas, partially covering parts of the accretion disk (e.g. Guilbert & Rees 1988). In the case of Mkn 335, the clouds must cover only the inner parts of the disk, since we find that the UV emission is not highly variable between the *XMM-Newton* observation in 2000 and the *Swift* observations in 2007, while the X-rays vary dramatically[3]. Note that the fits to the May 17 and May 25 Swift spectra suggest a change in the partial covering absorber column densities by a factor of about 2. This timescale is consistent with e.g. the absorber toy model suggested by Abrassart & Czerny (2000), where thick clouds at 10-100 Schwarzschild radii partially obcure the central region and causing the X-ray variability.

Alternatively, a partial covering situation may arise if our line-of-sight passes through an accretion-disk driven wind which is launched at intermediate disk radii (e.g. Elvis 2000; Proga 2007). If such a wind varies with time and/or is inhomogeneous, different parts of the central source would be covered at different times. In both partial covering geometries, the physics is still uncertain. In the case of dense blobs: how are they confined and what is their origin (e.g. Kuncic et al. 1997). In case of disk-driven winds: what is the driver of these massive outflows (e.g. Proga 2007).

The high column density we need in our SWIFT spectral fits is similar to those frequently observed in BAL quasars (e.g. Green & Mathur 1996; Gallagher et al. 2002; Grupe et al. 2003). In this context, it is interesting to note that similarities between NLS1 galaxies and BAL quasars have been pointed out repeatedly (e.g. Mathur 2000; Brandt & Gallagher 2000; Boroson 2002). In one specific case, that of the X-ray transient NLS1 galaxy WPVS 007, the onset of heavy X-ray absorption (Grupe et al. 2007b) is indeed accompanied by the onset of UV BALs (Leighly et al. in prep 2007). When correcting for the effects of intrinsic absorption we found that the X-ray flux of Mkn 335 originating from the central engine has been very similar in the rest-frame 0.2-2.0 keV band between the ROSAT observations and the most recent *Swift* observations. Using these fluxes, the intrinsic variability is only a factor of about 4-6, which is quite normal for an AGN, in particular for a NLS1. The change in intrinsic flux between the first and second Swift observations is about a factor of 3 within a week. If a partial covering absorber is the correct model this flux change implies that the soft X-ray scattering region can only be a few light days in diameter which is consistent with the Abrassart & Czerny (2000) toy model. The deep low-state of Mkn 335 discovered with *Swift* provides us with a rare chance to scrutinize the properties of X-ray low-state AGN in general. Mkn 335 is unique with respect to being relatively bright during its low-state. Therefore, follow-up observations of Mkn 335 in its current low-state are highly encouraged. We will continue our monitoring with *Swift* in order to find the timescales on which the AGN switches from a low to high state, but also deep *XMM-Newton* observations, optical spectrocsopy and spectropolarimetry are needed to clarify the nature of the current low-state.

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[3]We note that historic light curves from IUE and HST did show that Mkn 335 has been variable in the UV between 1978 and 1985 (Dunn et al. 2006; Edelson et al. 1990) by a factor of 2. The UBVRI photometry of Mkn 335 as reported by Doroshenko et al (2005) (see also Czerny & Janiuk (2007)) also suggests that the AGN is intrinsically highly variable. However, because of the lack of simultaneous X-ray observations during these time periods we do not know if the UV variability was caused by changes in the flux of the central engine or was caused by absorption.

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TABLE 1
XMM-Newton & *Swift* observations of Mkn 335

Mission	T-start[1]	T-stop[1]	T_{exp}[2]
XMM 2000	12-25 17:18	12-26 02:06	36910
XMM 2006	01-03 19:10	01-05 08:03	133251
Swift 001/2007	05-17 00:32	05-17 05:37	4860
Swift 002/2007	05-25 00:01	05-25 19:23	8084
Swift 003/2007	06-28 00:01	06-28 14:37	2932
Swift 004/2007	06-30 00:13	06-30 14.52	2837
Swift 005/2007	07-02 14:47	07-02 21:18	2979

[1]Start and End times are given in UT

[2]Observing time given in s

TABLE 2
Spectral analysis of the *XMM-Newton* and *Swift* X-ray data.

Observation	Model[1]	$\alpha_{X,soft}$	E_{break}[2]	$\alpha_{X,hard}$	$N_{H,pcf}$[3]	F_{cover}[4]	log $F_{X,gal}$[5]	log $F_{X,all}$[6]	χ^2/ν
XMM 2000	(a)	1.87±0.01	$1.76^{+0.09}_{-0.08}$	1.18±0.04	—	—	−13.10		513/419
	(b)	1.87±0.01	—	—	$7.7^{+1.1}_{-0.9}$	0.58±0.02	−13.10	−12.72	561/419
XMM 2006	(a)	1.73±0.01	1.82±0.02	1.08±0.01	—	—	−13.17		2420/1327
	(c)	1.74±0.01	1.63±0.03	1.25±0.02	$55.1^{+10.0}_{-8.2}$	$0.45^{+0.04}_{-0.03}$	−13.17	−12.91	1973/1325
	(d)	1.74±0.01	1.62±0.03	1.25±0.02	$51.0^{+10.2}_{-8.0}$	$0.43^{+0.04}_{-0.03}$	−13.17	−12.93	2611/1910[8]
Swift 001	(c)	$2.05^{+0.24}_{-0.20}$	—	—	$31.1^{+17.0}_{-13.6}$	$0.98^{+0.02}_{-0.03}$	−14.63		9/9
	(e)	1.74±0.01	1.62±0.03	1.25±0.02	$38.2^{+19.2}_{-19.6}$	$0.95^{+0.04}_{-0.03}$	−14.75	−13.48	2611/1910[8]
	(f)	1.79±0.10	—	—	$20.0^{+8.9}_{-5.4}$	0.93[7]	−14.71	−13.55	87/85[9]
	(g)	1.81±0.10	—	—	$20.5^{+8.6}_{-5.4}$	$0.94^{+0.01}_{-0.02}$	−14.70	−13.51	87/86[9]
	(h)	1.81±0.10	—	—	$12.8^{+2.6}_{-2.2}$	$0.91^{+0.03}_{-0.06}$	−14.72	−13.69	95/86[9]
Swift 002	(c)	1.78±0.14	—	—	$10.4^{+2.6}_{-2.2}$	$0.93^{+0.02}_{-0.03}$	−14.25	−13.10	52/48
	(e)	1.74±0.01	1.62±0.03	1.25±0.02	$10.4^{+3.6}_{-2.7}$	$0.88^{+0.02}_{-0.03}$	−14.27	−13.37	2611/1910[8]
	(f)	1.79±0.12	—	—	$10.4^{+2.6}_{-2.1}$	0.93±0.02	−14.25	−13.10	87/85[9]
	(g)	1.81±0.10	—	—	$10.9^{+2.4}_{-2.0}$	$0.94^{+0.01}_{-0.02}$	−14.25	−13.06	87/86[9]
	(h)	1.81±0.10	—	—	$12.8^{+2.6}_{-2.2}$	$0.94^{+0.01}_{-0.02}$	−14.25	−13.02	95/86[9]
Swift 003-005[10]	(c)	1.75±0.17	—	—	$16.6^{+6.4}_{-4.7}$	$0.93^{+0.02}_{-0.04}$	−14.49	−13.32	23/26
	(e)	1.74±0.01	1.62±0.03	1.25±0.02	$17.5^{+9.8}_{-6.6}$	$0.89^{+0.04}_{-0.07}$	−14.50	−13.56	2611/1910[8]
	(f)	1.79±0.10	—	—	$16.4^{+6.1}_{-4.6}$	$0.94^{+0.02}_{-0.03}$	−14.48	−13.28	87/85[9]
	(g)	1.81±0.10	—	—	$15.8^{+4.0}_{-3.2}$	$0.94^{+0.01}_{-0.02}$	−14.47	−13.28	87/86[9]
	(h)	1.81±0.10	—	—	$12.8^{+2.6}_{-2.2}$	$0.92^{+0.02}_{-0.03}$	−14.48	−13.36	95/86[9]

[1]Spectral models used are: (a) absorbed power law, (a) absorbed broken power law, (b) partial covering absorbed with a single power law, (c) partial covering absorber and broken power law, (d) same as (c) but simultaneous fits to the 2006 *XMM-Newton* and all *Swift* spectra with the broken power law parameters tied and the partial covering absorber parameters left free to vary, (e) same as (b) but *Swift*spectra fit simultaneously in XSPEC with the X-ray spectral index tied and the partial covering absorber parameters left free to vary, (f) same as (e) but the covering fraction f_c of all three *Swift* spectra tied, and (g) same as (e) but N_H tied and f_c left free. For all models the absorption column density was fixed to the Galactic value (3.96×10^{20} cm^{-2} Dickey & Lockman 1990).

[2]The break energy E_{break} is given in units of keV.

[3]Absorption column density of the redshifted partial covering absorber $N_{H,pcf}$ in units of 10^{22} cm^{-2}

[4]Covering fraction F_{cover}

[5]Rest-frame 0.2-2.0 X-ray flux log $F_{0.2-2.0keV}$ corrected for Galactic absorption given in units of W m^{-2}

[6]Rest-frame 0.2-2.0 X-ray flux log $F_{0.2-2.0keV}$ corrected for Galactic and intrinsic absorption given in units of W m^{-2}

[7]eaving covering absorber fraction as a free only gives an unconstrained results. We therefore fixed the absorption covering fraction to 0.93 which was found in the other *Swift* data.

[8]Simultaneous fit to all *Swift* data

[9]Simultaneous fit to all *Swift* data

[10]Coadded data from segments 003 to 005

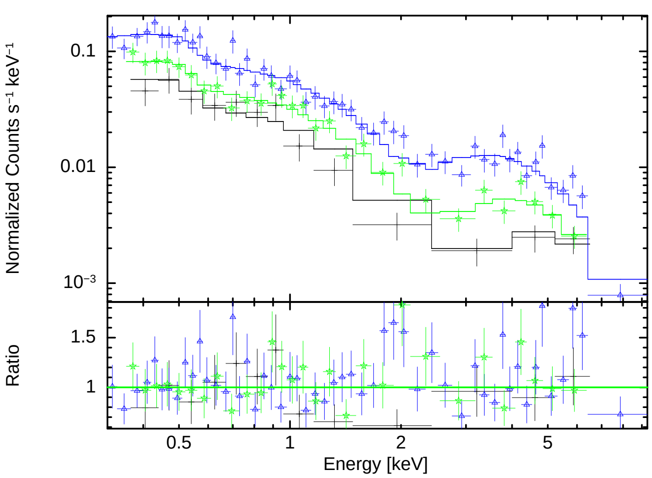

Fig. 1.— *Swift*-XRT spectra of Mkn 335 fitted with a power law model with partial covering absorber as listed in Table 2. The black spectrum displays the *Swift* segment 001 spectrum, the segment 002 spectrum is in blue (triangles), and the segment 003-005 spectrum in green (stars).

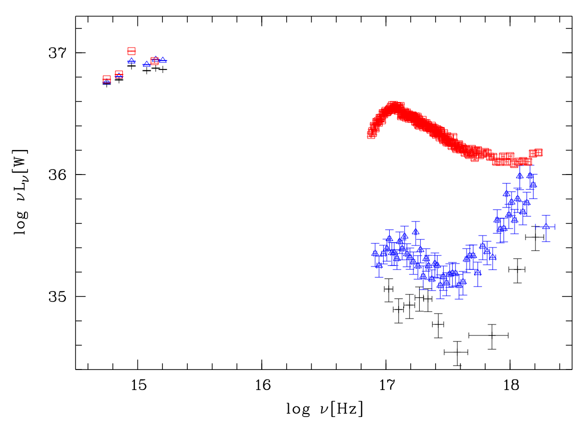

Fig. 2.— Spectral energy distributions of Mkn 335. The black crosses are from the *Swift*observation segment 001, blue triangles form segment 002, and red squares from the 2000 *XMM-Newton* observation. The *Swift* segments 003-005 spectrum would be between the 001 and 002 spectra.